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A STUDY OF THE DECREASE IN FALSE ALARM PROBABILITY RESULTING FR--ETC(U)

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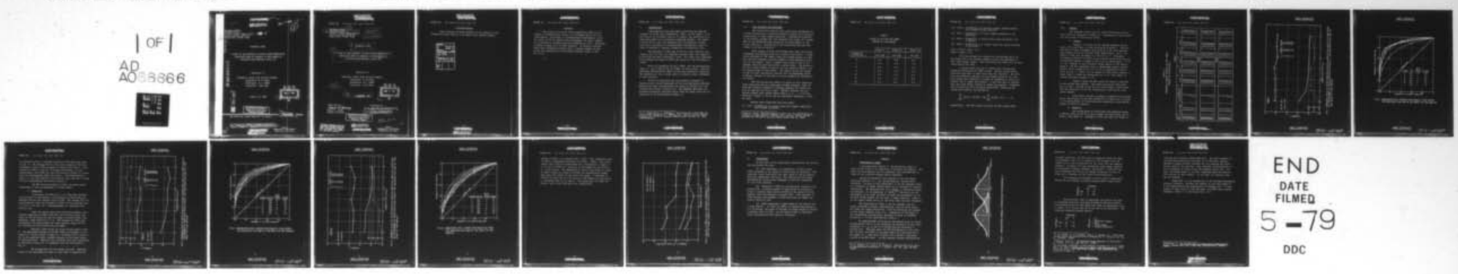

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TECHNICAL NOTE

A STUDY OF THE DECREASE IN FALSE ALARM PROBABILITY RESULTING FROM AN INCREASE IN THE NUMBER OF DISPLAYED ECHO RANGING CYCLES (U)

Submitted to

Commander, Naval Ship Systems Command
Department of the Navy
Washington, D.C. 20360
Attention: Code 1631

August 19, 1966

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12 24p.

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ABSTRACT

The reduction in false alarm probability P(FA) as the number of displayed echo cycles n is increased from 6 to 12 is investigated. According to a predetermined experimental curve, the value of S/N is reduced with increasing n in such a manner as to maintain a constant detection probability, P(C). Decreases in P(FA) as great as 0.19 were observed. To obtain a minimum P(FA) while retaining constant P(C), a greater number of echo cycles are required for the initially smaller values of S/N for n = 6.

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I. INTRODUCTION

Investigations have been made concerning the expected decrease in false alarm probability, P(FA), as the number, n, of echo-cycles is increased from six to twelve, one echo-cycle at a time being added to an intensity modulated display. The signal-to-noise ratio, S/N, was decreased with the addition of each echo-cycle according to a predetermined experimental curve[1] in order to maintain a constant probability of detection, P(C).

The decrease in P(FA) was 0.19 for a test condition providing a P(C) of 0.81, but remained constant after the number of echo-cycles had been increased to nine. For other test conditions a more gradual decrease in P(FA) was noted as n was increased to eleven.

Plots are presented of P(C), P(FA), and the detectability index, d', as a function of the number of echo-cycles. Receiver operating characteristic (ROC) curves were obtained by requiring the observers to use a rating scale to indicate their confidence in each decision.

Section II describes the test material presented to observers and a brief discussion of the test procedures employed. Results and their interpretation are given in Section III; conclusions are listed in Section IV. The appendix describes the multiple-alternative decision matrix used for these tests and its reduction to the detectability index, d'.

[1] J. M. Young and D. E. Robinson, "Processing Gain Achievable by Ping-to-Ping Integration," TRACOR, Inc., Austin, Texas, TRACOR Document No. 64-221-C, Contract NObsr-91223, October 22, 1964, (CONFIDENTIAL).

II. TEST MATERIAL AND PROCEDURE

The film-strips used for this study were photographs of a computer-generated, intensity-modulated display with intensity proportional to input sample amplitude. Information presented on the display cathode-ray tube simulated the output of a single beam of the AN/SQS-26 sonar system as it would appear on the A-scan indicator. Generation of the film-strips has been described in an earlier report.[2]

Three groups of seven film-strips were used, each group containing successively from six to twelve echo-cycles. A film-strip consisted of 150 frames, each with common values of n and S/N, and with randomly injected signals in approximately 50 percent of the frames. Also, a signal could occur in one of six randomly selected positions within a given frame. The values of S/N for a given number of echo-cycles are listed in Table I for the three groups of film-strips. The values of S/N for Groups II and III were successively reduced from corresponding values in Group I because of the high detection probability afforded by the latter.

The film-strips were shown to a group of four observers. These observers were all young male college students, three of whom had recently completed a training program; the fourth has been an observer for over a year. During a session, the observers marked their answer sheets with a 1, 2, ..., 6 if they detected a signal in one of the six positions; otherwise, a zero was used.

Results were classified into five parts:

(1) P(C) = Probability of correct detection (signal identified and located correctly).

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[2]James M. Young, "Marking Density Studies for the AN/SQS-26 Sonar Equipment A-Scan Display," TRACOR, Inc., Austin, Texas, TRACOR Document No. 66-316-U, Contract NObsr-95149, May 20, 1966.

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TABLE I

VALUES OF S/N FOR THE THREE
GROUPS OF FILM-STRIPS

	Group I	Group II	Group III
Number of Echo-Cycles, n	S/N (dB)	S/N (dB)	S/N (dB)
6	9.0	8.6	8.2
7	8.7	8.2	7.7
8	8.3	7.9	7.5
9	8.0	7.5	7.2
10	7.7	7.3	6.9
11	7.4	7.1	6.6
12	7.3	6.9	6.5

(2) P(IT) = Probability of incorrect target (signal present, but assigned wrong location).

(3) P(M) = Probability of a miss (signal present but not detected).

(4) P(FA) = Probability of false alarm (noise believed to be a signal).

(5) P(CR) = Probability of a correct rejection (noise believed to be noise).

$P(C) + P(IT) + P(M) = 1.0$

$P(FA) + P(CR) = 1.0$

The time allowed for viewing the film-strips was 6 sec per frame with 3 sec between frames to allow the observers to mark their answer sheets. Each film-strip was shown four or more times during the study.

A rating scale was used to obtain data for Receiver Operating Characteristic (ROC) curves. Using a rating scale, observers were made to adopt more than one criterion. Not only were the observers required to note signal position, but they also rated their responses 1 through 4, depending on their confidence that a signal was present. A zero was used to indicate that they were almost certain no signal was present. Probabilities of detection P(D) and false alarm P(FA), employing the rating scale method, are defined as

$$\sum_{k=1}^{4} [P_k(C) + P_k(IT)] \text{ and } \sum_{k=1}^{4} P_k(FA),\ k=1, \ldots, 4,$$

respectively. The ROC curves are plots of P(D) versus P(FA).

III. RESULTS

The observed results for all of the film-strips used in this study are presented in Table II. Discussions of the results for each group of film-strips follow.

A. Group I

Figure 1 is a plot of the average observer performance, P(C) and P(FA), on each film-strip of Group I. The average value of P(C) throughout this group is 0.81, with maximum and minimum values of 0.82 and 0.78, respectively. For $n = 6$, P(FA) is 0.38, but decreases to 0.25 for $n = 7$. Although a continuous reduction of P(FA) occurs as echo-cycle histories are successively added, a change of only 0.03 is noted from $n = 8$ to $n = 12$. Because of the relatively large values of S/N used in Group I, and the consequent ease in discerning signals, detectability is not enhanced for $9 < n \leq 12$, as depicted by the d' curve in Fig. 1. Thus, for the number of echo-cycles studied, a lower limit to P(FA) was approached for $n = 9$, with almost no further decrease through $n = 12$.

Figure 2 shows the ROC curves for Group I, obtained by the rating scale method. The twelve echo-cycle film-strip was not used. The ROC curves for all other Group I film-strips, with the exception of the one containing 11 echo-cycles, show little spread.

Since P(FA) reaches a minimum so rapidly with increasing n, and because of the high probability of detection for Group I, two other groups of film-strips were generated, using smaller values of S/N for a given n.

B. Group II

The second group of film-strips was generated using a smaller value of S/N for a given number of echo-cycles than in Group I (See Table I). Averages of P(C) and P(FA) for Group II

TABLE II

OBSERVERS AVERAGE RESULTS ON THE THREE GROUPS OF FILM-STRIPS

Run No.	S/N (dB)	n, Number of Echo-Cycles	P(C)	P(IT)	P(M)	P(FA)	P(CR)	d'
			GROUP I					
471	9.0	6	0.82	0.07	0.11	0.38	0.62	1.52
472	8.7	7	0.82	0.04	0.14	0.25	0.75	1.88
473	8.3	8	0.82	0.04	0.14	0.22	0.78	1.90
474	8.0	9	0.84	0.03	0.13	0.21	0.79	1.94
475	7.7	10	0.78	0.04	0.18	0.20	0.80	1.76
476	7.4	11	0.80	0.04	0.16	0.21	0.79	1.80
477	7.3	12	0.79	0.05	0.17	0.19	0.81	1.91
			GROUP II					
485	8.6	6	0.67	0.08	0.25	0.25	0.75	1.34
486	8.2	7	0.68	0.06	0.26	0.19	0.81	1.52
487	7.9	8	0.68	0.04	0.28	0.15	0.85	1.62
488	7.5	9	0.63	0.05	0.32	0.13	0.87	1.60
489	7.3	10	0.63	0.05	0.32	0.14	0.86	1.55
490	7.1	11	0.67	0.03	0.30	0.09	0.91	1.78
491	6.9	12	0.64	0.04	0.32	0.14	0.86	1.55
			GROUP III					
478	8.2	6	0.54	0.12	0.34	0.33	0.67	0.85
479	7.7	7	0.53	0.15	0.32	0.31	0.69	0.97
480	7.5	8	0.53	0.13	0.34	0.30	0.70	0.93
481	7.2	9	0.57	0.13	0.30	0.24	0.76	1.23
482	6.9	10	0.52	0.14	0.34	0.21	0.79	1.22
483	6.6	11	0.51	0.12	0.37	0.19	0.81	1.21
484	6.5	12	0.58	0.11	0.31	0.20	0.80	1.34

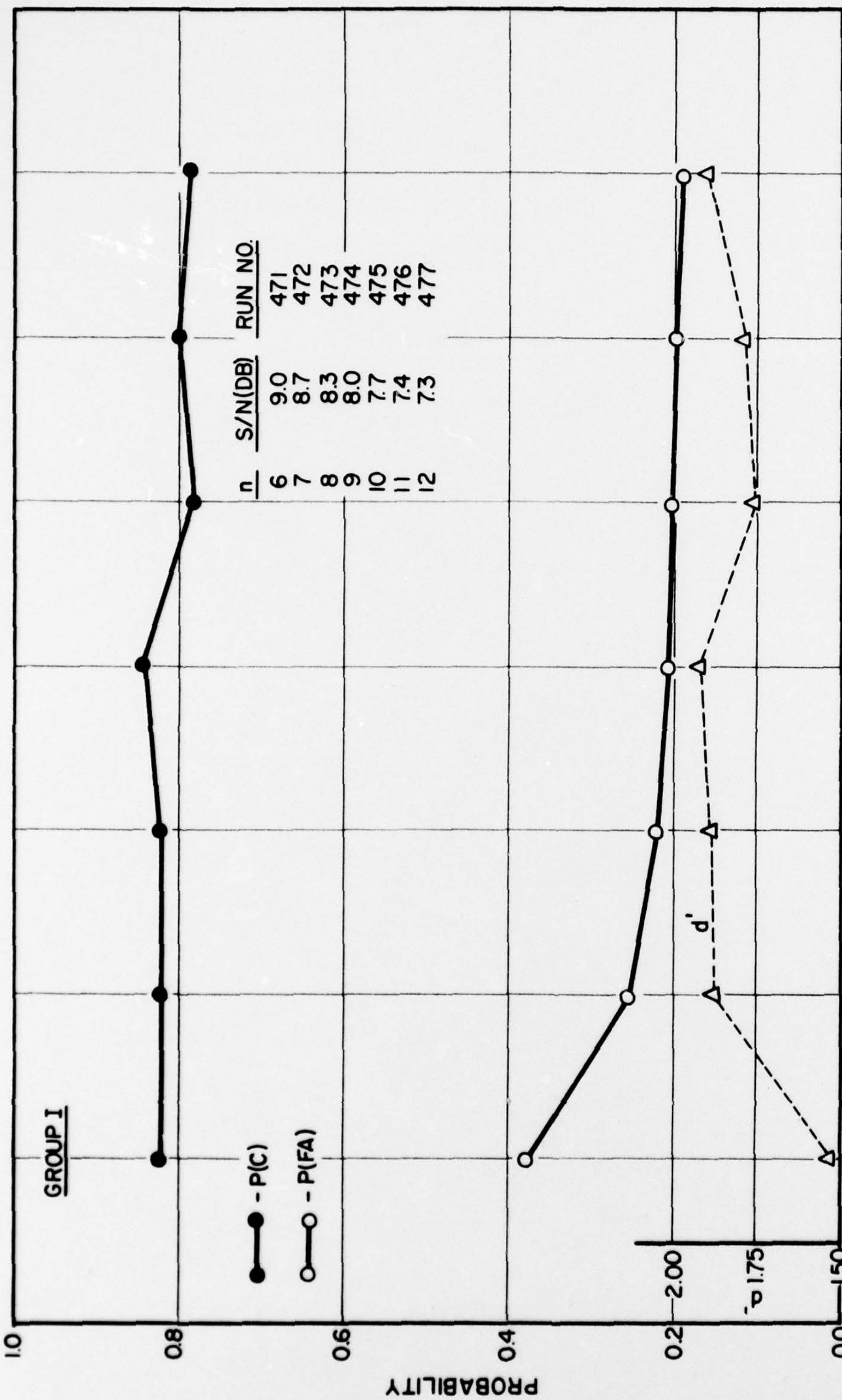

FIG. 1 - PROBABILITIES OF DETECTION, P(C), FALSE ALARM, P(FA), AND d' AS FUNCTIONS OF THE NUMBER OF DISPLAYED ECHO CYCLES, n. THE INDICATED S/N ARE AT THE INPUT TO THE DISPLAY.

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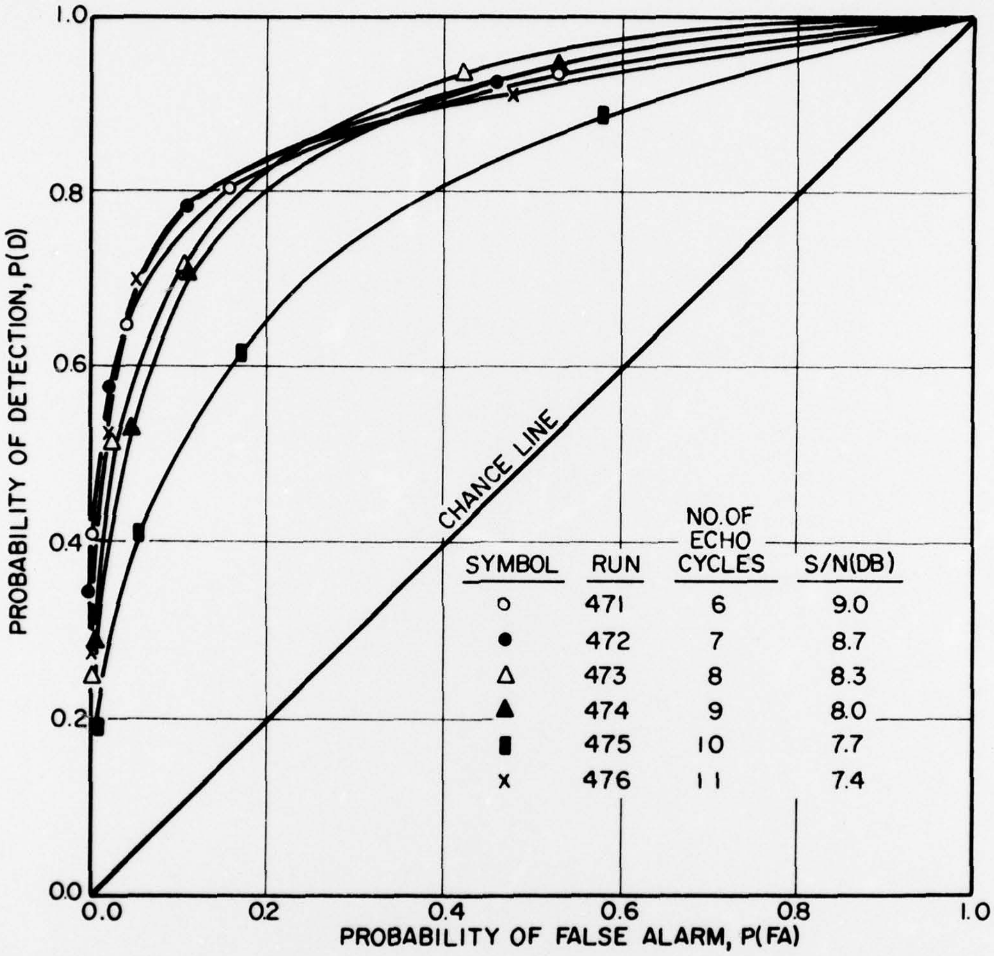

FIG.2 - OBSERVER'S ROC CURVES FOR GROUP I FILM STRIPS.
THE INDICATED S/N ARE AT THE INPUT TO THE DISPLAY.

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are plotted in Fig. 3, and ROC curves for this group are shown in Fig. 4. The average P(C) for the entire group is 0.66; the decreasing trend in P(FA) extends to eleven echo-cycles. Total decrease in P(FA), from six to eleven echo-cycles, is 0.16. Surprisingly, each P(FA) for the film-strips in Group II is less than the corresponding P(FA) for Group I. The detectability index, d', for each Group II film-strip is less than the d' value for the corresponding film-strip of Group I.

The ROC curves for Group II (Fig. 4) relate almost identically to the corresponding d' values listed.

C. <u>Group III</u>

To increase the P(FA) for n = 6, from that obtained for the Group II film-strips, a third group of film-strips was prepared with an even smaller value of S/N. The average P(C) for this group was 0.54; the decrease in P(FA) of 0.13 occurred from n = 6 to n = 12 (Fig. 5). Correspondingly, d' increased from 0.85 to 1.34.

Since the twelve echo-cycle film-strip showed a substantial reduction in P(FA) from that for six echo-cycles, the value of S/N for Group III was low enough to prevent P(FA) from reaching a lower bound for $n < 12$. The decrease in P(FA) with increasing n was more gradual for these smaller values of S/N, but continues as more echo-cycles are added.

Observer's ROC curves for Group III are shown in Fig. 6. The approximate spread of the ROC curves corresponds to the range of d' values listed in Table II. Grouping of the curves is not in the expected order, probably because of the large values of P(IT) and P(FA). Figure 6 thus indicates that less consistency is afforded by Group III, in agreement with the P(C) graph of Fig. 5.

The average P(C) for all groups was 0.67. Observed values of the detectability index d' were used to normalize all

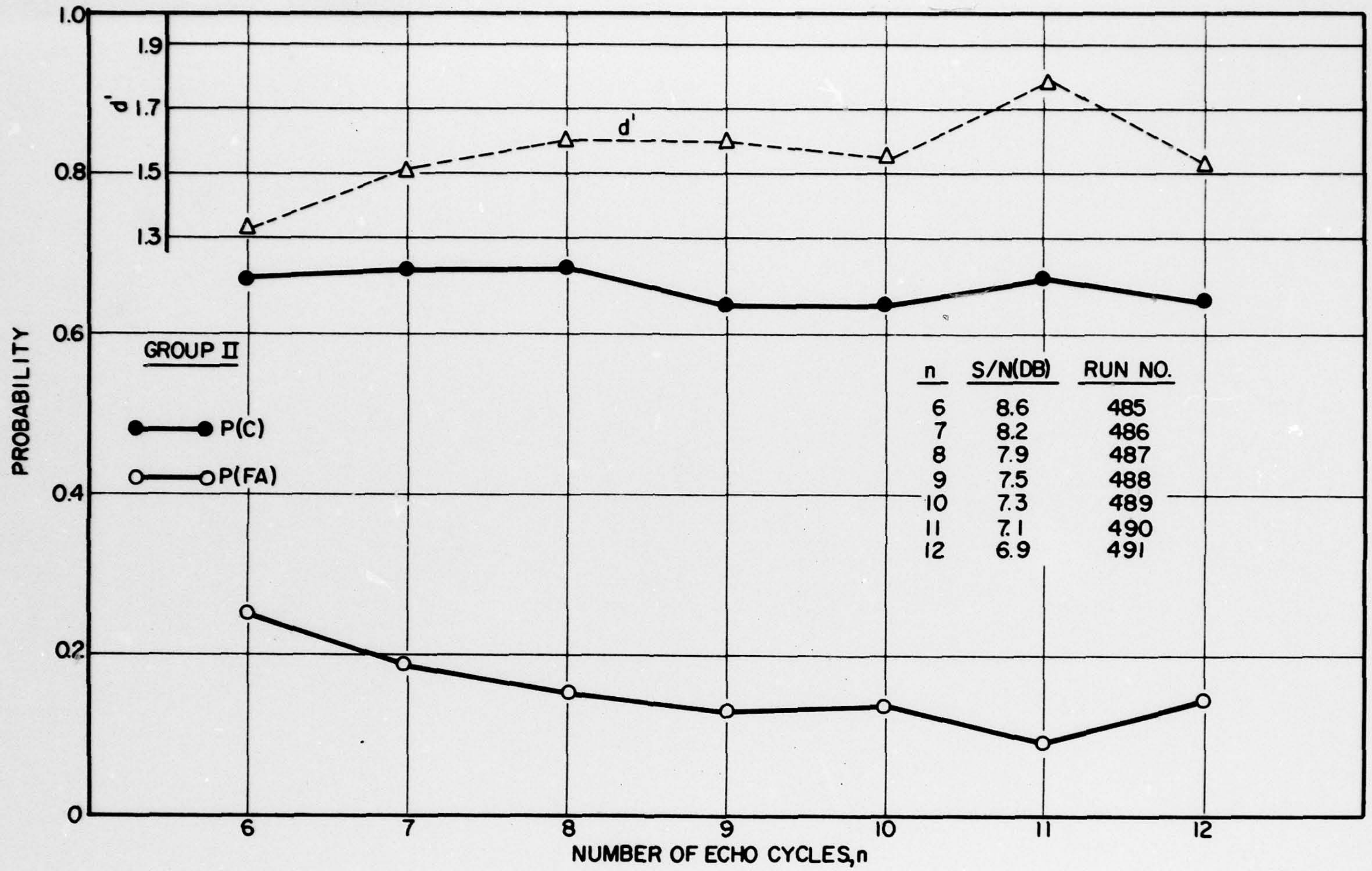

FIG. 3 -PROBABILITIES OF DETECTION, P(C), FALSE ALARM, P(FA), AND d' AS FUNCTIONS OF THE NUMBER OF DISPLAYED ECHO CYCLES. THE INDICATED S/N ARE AT THE INPUT TO THE DISPLAY.

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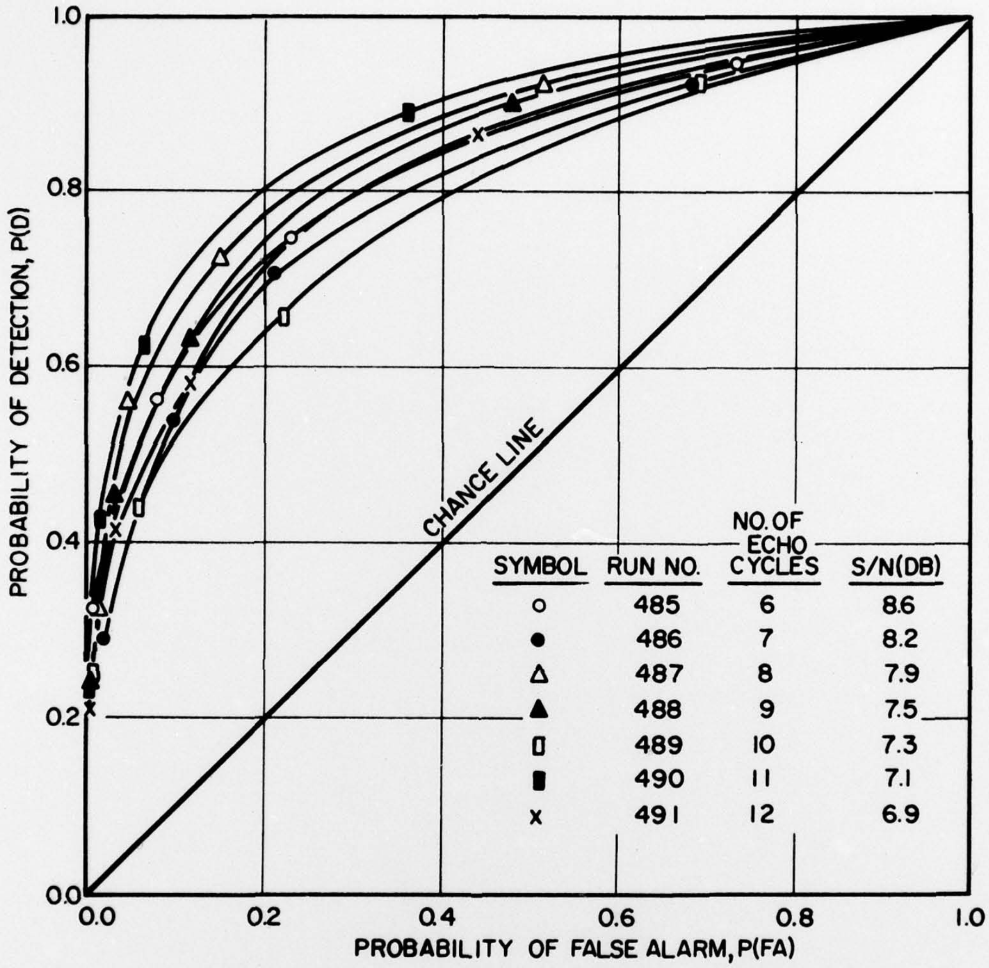

FIG. 4 – OBSERVER'S ROC CURVES FOR GROUP II FILM STRIPS.
THE INDICATED S/N ARE AT THE INPUT TO THE DISPLAY.

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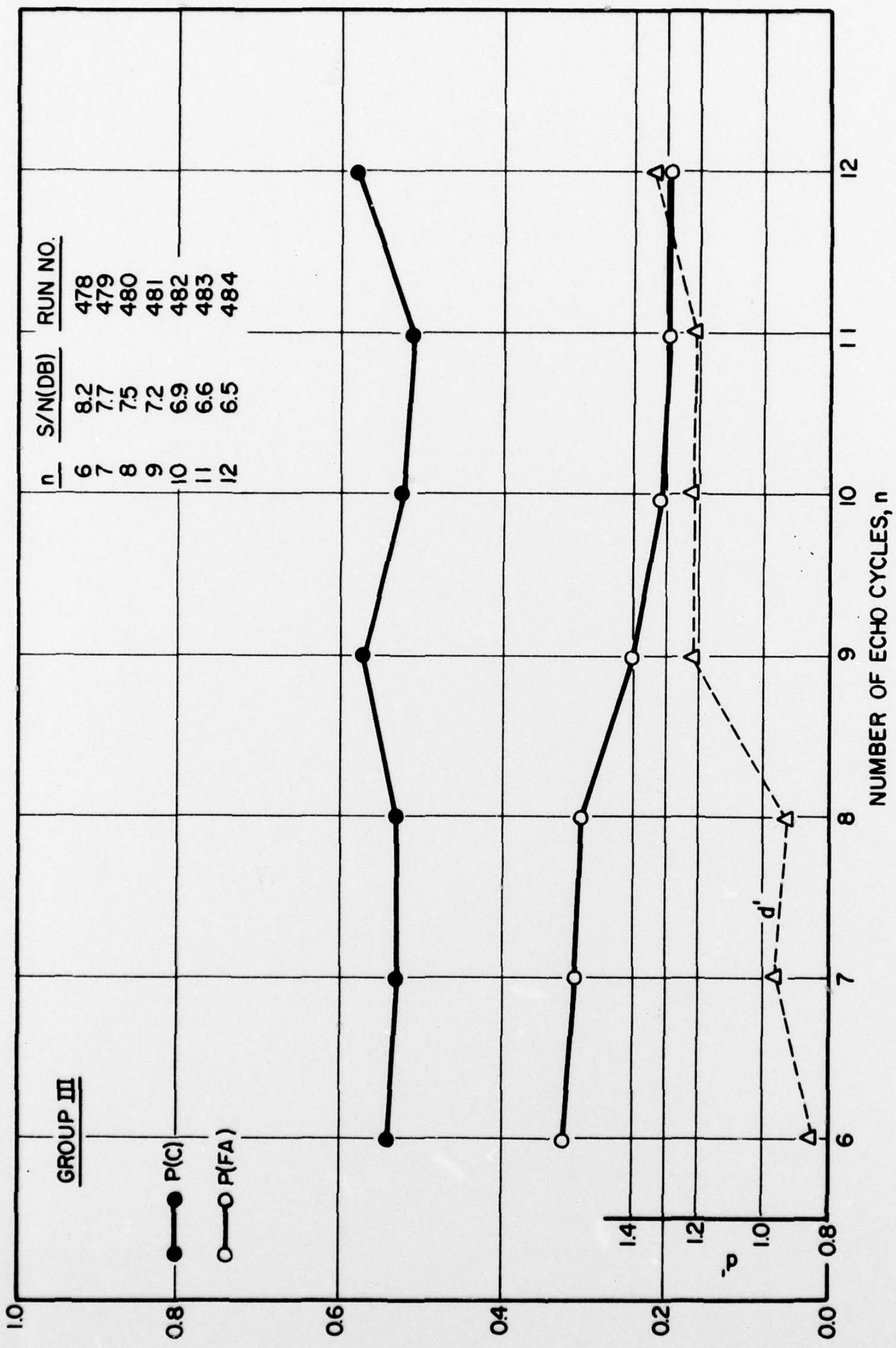

FIG. 5 – PROBABILITIES OF DETECTION, P(C), FALSE ALARM, P(FA), AND d' AS FUNCTIONS OF THE NUMBER OF DISPLAYED ECHO CYCLES. THE INDICATED S/N ARE AT THE INPUT TO THE DISPLAY.

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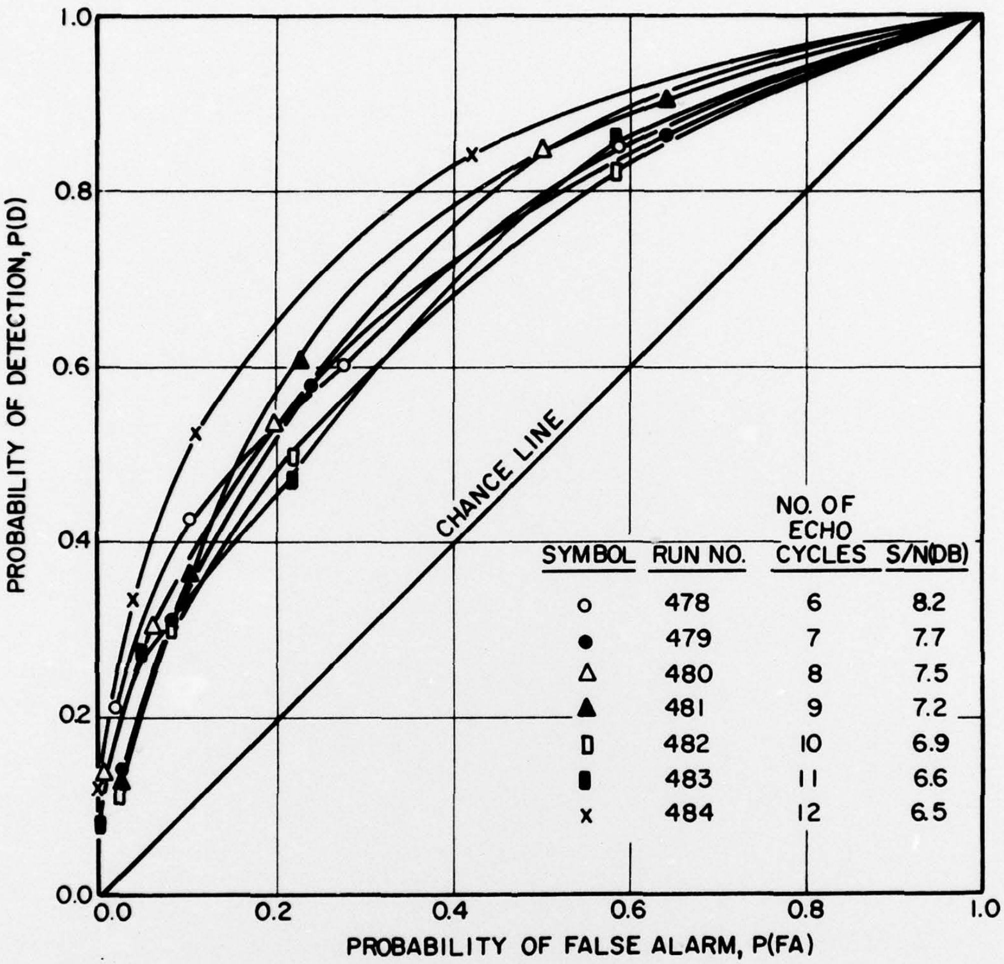

FIG. 6 - OBSERVER'S ROC CURVES FOR GROUP III FILMS. THE INDICATED S/N ARE AT THE INPUT TO THE DISPLAY

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values of P(FA) to a constant P(C) = 0.65. This normalized value of P(FA) is designated hereafter by P*(FA). (Note: This value rather than 0.67 was chosen merely for convenience.) Figure 7 is a plot of P*(FA) as a function of the number of echo-cycles, n, in each group. The separation of Group I and Group II curves is small; Group III values of P*(FA) are substantially higher than those for either of the first two groups. A decrease in P*(FA) for Group III of 0.15 occurs as the number of echo-cycles is increased from six to twelve. The reductions in P*(FA) for Groups I and II are 0.09 and 0.12, respectively.

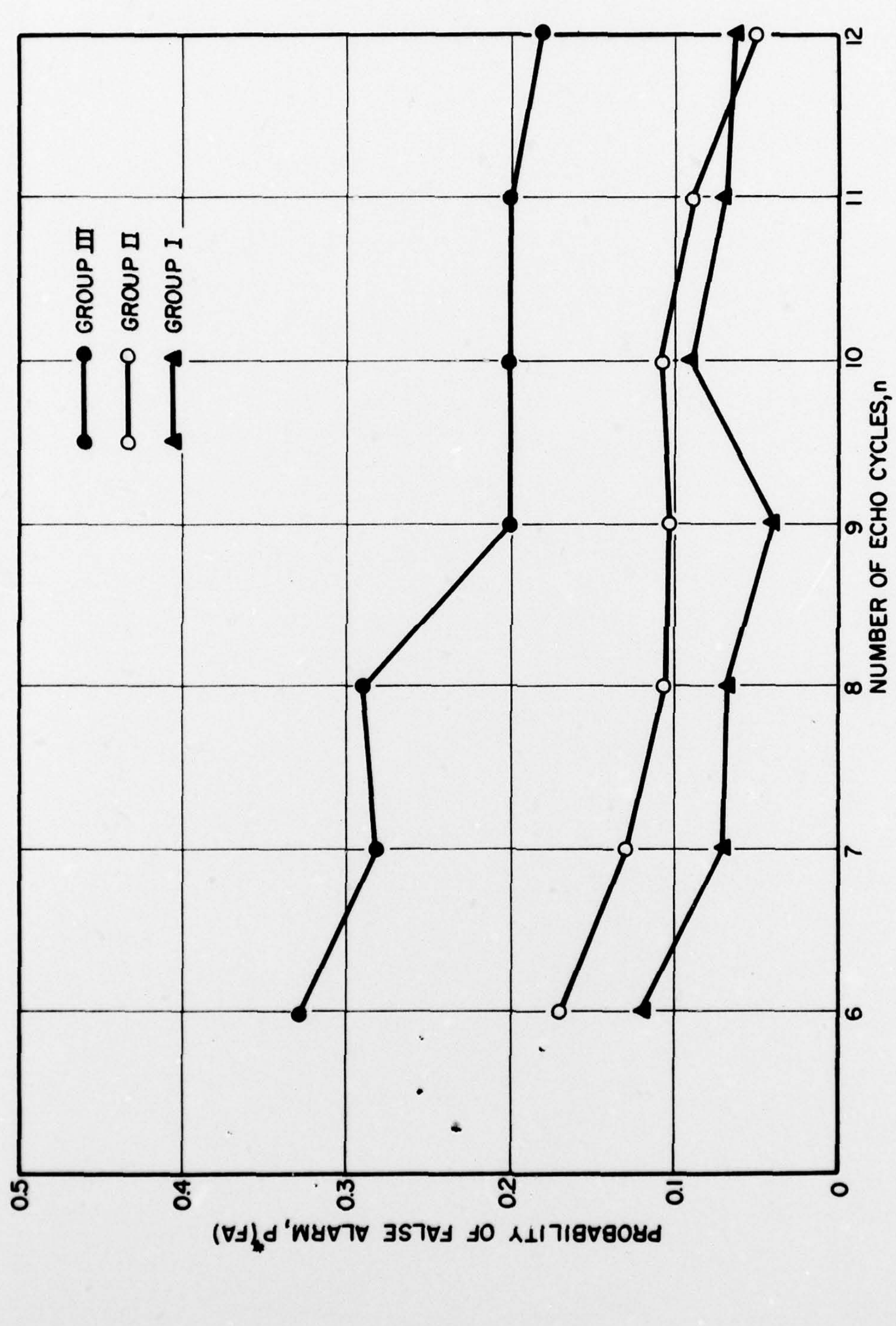

FIG.7-VALUES OF $P^*(FA)$ FOR A CONSTANT PROBABILITY OF DETECTION $P'(C)=0.65$ FOR THE THREE GROUPS OF FILM STRIPS LISTED IN TABLE I.

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VI. CONCLUSIONS

On the basis of the experiments reported here the following conclusions are made:

(1) The likelihood, or probability, of false alarm P(FA) decreases as the number of echo-cycles is increased. The reduction occurs even while the input value of S/N is reduced with each additional echo-cycle, the reduction in S/N being determined by previous data designed to hold the likelihood of a hit P(C) constant.

(2) Reduction in P(FA) is curvilinearly related to the initial S/N. A greater number of echo-cycles is required to attain a constant lower bound on P(FA) as the value of S/N is reduced, while maintaining a constant P(C). This decrease in P(FA) becomes more gradual, as each echo-cycle is added, for smaller values of S/N.

(3) P(FA) approaches a lower bound as the initial S/N is made smaller. In order for P(FA) to continue decreasing as n is increased, the value of S/N must be large enough to provide a constant value of P(C). As the value of S/N is decreased, P(IT) increases and P(C) begins to fluctuate.

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APPENDIX

I. DETECTABILITY INDEX

A psychophysical measure d' (detectability index) is used in this study as an indication of observer performance. The basis for this measure will be explained, and reinterpreted in terms of the stimulus-response matrix employed.

Tanner and Birdsall[3] have defined d' for the binary detection problem, i.e., the two-alternative, forced-choice situation. As used in this memorandum, d' may be regarded either as a function of signal effectiveness or as a measure of observer sensitivity. The detectability of a signal, as defined by Tanner and Birdsall, is the magnitude of $(2E/N_o)^{1/2}$ necessary for the performance of an ideal receiver to match the performance of the receiver being studied (in our case, a human observer). Here E is the signal energy and N_o is the noise power per unit bandwidth.

The detectability index d' may be obtained from two normal probability density distributions, one for noise alone, the other for signal-plus-noise. Both distributions are assumed to have equal variance (Fig. A-1). Separation of the means of the overlapping distributions, measured in units of standard deviation, σ, is the detectability index d'.

An idealized ROC curve may be constructed from the normal distributions (Fig. A-1) by requiring the observers to vary their criterion, C (e.g., by use of a rating scale as discussed in Section III). The area under the S+N distribution to the right of C is P(C), and P(FA) is the area under the N distribution to the right of C. Each pair of areas, for a given C, determine a point on an ROC curve. In this instance (normal distributions

[3]W. P. Tanner, Jr., and T. G. Birdsall, "Definitions of d' and η as Psychophysical Measures," J. Acoust. Soc. Am., 30, 922-928, (1958).

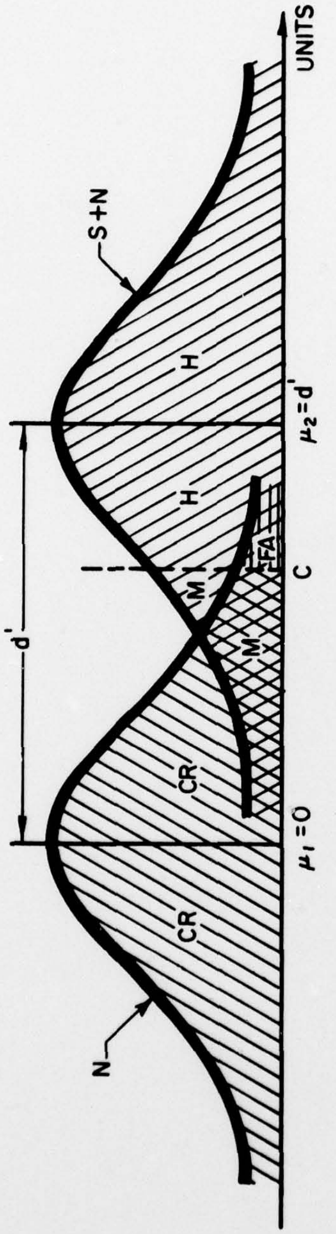

FIG. A-1 - OVERLAPPING NORMAL DISTRIBUTIONS FOR OBTAINING d'

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of equal variance), the ROC curve is symmetric about the negative diagonal, and d' is a measure of the distance from the chance line to the intersection of the curve with the negative diagonal. Allowance for test hypotheses with unequal variance is discussed by Clarke, Birdsall, and Tanner[4]. Jeffress[5] has also considered the effects of unequal variances, as well as those due to skewness of the N and S+N distributions.

The foregoing has assumed a yes-no type of experiment[6], having the four-element stimulus-response matrix shown below.

RESPONSE		STIMULUS S+N	STIMULUS N
	S+N	H	FA
	N	M	CR

The particular type of experiment with which this note is concerned involves a multiple-alternative decision problem. Discrimination must be made among more than two hypotheses, e.g., a signal, if it occurs, may be in any one of six positions. The resulting stimulus-response matrix:

RESPONSE		STIMULUS S+N	STIMULUS N
	S+N	C IT	FA
	N	M	CR

C - Hit
IT - Incorrect Target
M - Miss
FA - False Alarm
CR - Correct Rejection

---

[4] F. R. Clarke, T. G. Birdsall, and W. P. Tanner, Jr., "Two Types of ROC Curves and Definitions of Parameters," J. Acoust. Soc. Am., 31, 629-630, (1959).

[5] Jeffress, Lloyd A., "Stimulus-Oriented Approach to Detection," J. Acoust. Soc. Am., 36, 766-774, (1964).

[6] An excellent treatment of this subject is given in: D. M. Green and J. A. Swets, Signal Detection Theory and Psychophysics, John Wiley and Sons, Inc., New York, (1966). See especially the material in Chap. 2.

contains five elements rather than four. The extra element for the multiple-alternative situation is IT (incorrect target), meaning a signal actually occurred but its location was incorrectly noted by the observer. Now, possible interpretations of the IT response in terms of the four-element matrix are: (1) Miss, (2) False Alarm, or (3) Hit, depending upon the relative cost factors of each element. In our case, no relevant costs may be assigned.

Middleton[7], in his formulation of the multiple-alternative decision situation, includes the element IT with the element M in his determination and minimization of average risk. A consequence of this choice is that the point on an ROC curve corresponding to P(FA) = 1.0 will have P(D) < 1.0.

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[7]Middleton, D., An Introduction to Statistical Communication Theory, McGraw-Hill, Inc., New York, Section 23.1, (1960).